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by

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TWO DIMENSIONAL MODIFICATIONS OF GAUSSIAN LASER LIGHT BUNDLES

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SUMMARY

This presents, under the effects of a two-dimensional standing wave acoustic field, a two-dimensional theory for form modifications in the spacial strengths of Gaussian laser light bundles or beams. The results of experimentation and theory agree with each other. Under the appropriate ultrasonic power, the strength of faculae center domains tend toward uniformity. Moreover, the degree of uniformity and the range of it can be adjusted. Because of this, it has even more practical significance.

I

In reference [1], the author already provided the theory for one dimensional standing wave acousto-optical modifications of Gaussian laser bundles as well as his experimental results. However, in actual practical applications, there is a requirement for two dimensional modifications of laser bundles or beams. Because of this, as far as two dimensional acousto-optical modifications of form are concerned, we carried out a theoretical analysis. The help of computer assisted calculations as well as the relevent tests that were used showed clearly that, in two dimensional situations, if one obtains a laser beam with satisfactory continuity, it is possible to control the form modification. Still, it is necessary, as far as the relevent parameters are concerned, to make a reasonable selection. This article gives the selection ranges for these relevent parameters.

II

In two dimensional conditions, the light field distributions of Gaussian light bundles or beams can be written in the form below [2].

$$E(x, y, z', t) = (W_0/W)\exp\{[-(x^2+y^2)/W] + i[\omega t - \psi(z')]\}, \qquad (1)$$

In this equation, the significance of the relevent parameters is as shown in Fig.1. Among them, W_0 is the bundle or beam waist radius. W is the faculae radius at the location z' on the front surface of the acousto-optical device. ω and ψ are, respectively, the angular frequency and the phase of the light field. Due to the acousto-optical effects, after the light beam passes through acousto-optical devices, the phase will produce a change $\Delta\phi$. Because of this, at a location z on the back surface of acousto-optical devices, the light field should be written as:

$$E(x, y, z, t) = E(x, y, z', t)\exp(-i\Delta\phi)。 \quad (2)$$

On the lens L_2's back focal surface, one then has:

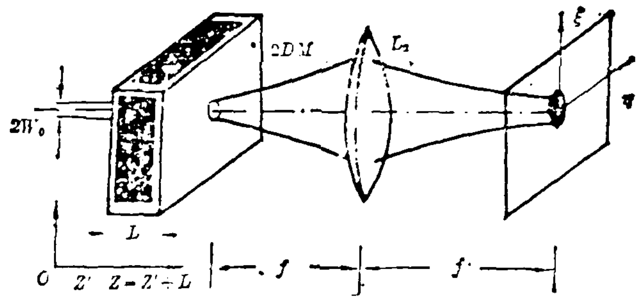

Fig. 1 Schematic diagram of intensity modification

$$I(\xi, \eta, t) = \left|\iint E(x, y, z, t)\exp(-iK(x\xi + y\eta)/f)dx\,dy\right|^2, \quad (3)$$

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In this, $K = 2\pi/\lambda$. λ is the light wave wavelength. f is the focal distance of the lens L_2. If one lets what the acousto-optical device adds be the two dimensional non-correlation ultrasonic field, then, the phase change caused by this should be:

$$\Delta\phi = 2KLn_0 + KL[\Delta n_x \sin(\omega_{sx}t + K_{sx}x) + \Delta n_x \sin(\omega_{sx}t - K_{sx}x)] + KL[\Delta n_y \sin(\omega_{sy}t + K_{sy}y) + \Delta n_y \sin(\omega_{sy}t + K_{sy}y)]。 \quad (4)$$

If the two dimensional field is of the same frequency as well as correlative, then, one has:

$$\begin{aligned}\Delta\phi = 2KLn_0 + KL[\Delta n_x \sin(\omega_s t + K_s x) + \Delta n_x \sin(\omega_s t - K_s x)] \\ + KL[\Delta n_y \sin(\omega_s t + K_s y + \phi) + \Delta n_y \sin(\omega_s t - K_s y + \phi)],\end{aligned} \tag{5}$$

In this equation Δn_x and Δn_y, respectively, represent the amplitude values for changes in the rates of refraction in the x and y directions after the addition of the acoustic field. ω_{sx} and ω_{sy}, respectively, represent the acoustic or sound wave circle frequencies in the x direction and y direction. K_{sx} and K_{sy}, then, respectively represent the sound wave wave vectors in the x direction and y direction. When two dimensional sonic fields have the same frequencies and are correlative, one has $\omega_{sx} = \omega_{sy} = \omega_s$ and $K_{sx} = K_{sy} = K_s$. ϕ is the phase difference between the sonic fields in the x direction and the y direction.

Take equation (4) and substitute into equation (2). In conjunction with this, going through the operations of equation (3), it is possible to obtain:

$$\begin{aligned}I(\xi, \eta, t) = \Big| \iint_{-\infty}^{\infty} (W_0/W)\exp[-(x^2+y^2)/W^2] \sum_{m=-\infty}^{\infty} J_m(v_x)\exp[-im(\omega_{sx}t - K_{sx}x)] \\ \times \sum_{n=-\infty}^{\infty} J_n(v_x)\exp[-in(\omega_{sx}t + K_{sx}x)] \sum_{p=-\infty}^{\infty} J_p(v_y)\exp[-ip(\omega_{sy}t + K_{sy}y)] \\ \times \sum_{l=-\infty}^{\infty} J_l(v_y)\exp[-il(\omega_{sy}t - K_{sy}y)]\exp[-iK(x\xi + y\eta)/f]\,dx\,dy \Big|^2 \\ = \pi W_0^2 W^2 \exp\{-W^2/2[(K\xi/f) + K_{sx}(n-m)]^2 \\ - W^2/2[(K\eta/f) + K_{sy}(p-l)]^2\} \\ \times \sum_{n=-\infty}^{\infty} \sum_{m=-\infty}^{\infty} J_m(v_x) J_n(v_x)\exp[-i\omega t(m+n)] \\ \times \sum_{p=-\infty}^{\infty} \sum_{l=-\infty}^{\infty} J_p(v_y) J_l(v_y)\exp[-i\omega t(p+l)]\Big|^2 .\end{aligned} \tag{6}$$

Let $\alpha = WK\xi/\sqrt{2}f$; $\beta = WK\eta/\sqrt{2}f$; $C_x = 2W/\Lambda_{sx}$; and, $C_y = 2W/\Lambda_{sy}$. Here, Λ_{sx} and Λ_{sy}, respectively, are the sound wave wavelengths in the x and y directions. $J_i(v)$ is the first type ith order Bessel function. Its argument v_x (or v_y) has $v_x = KL\Delta n_x$ ($v_y = KL\Delta n_y$). Because of this, equation (6) can be written as:

$$I(\alpha, \beta, t) = \pi^2 W'_0 W'^2 \left| \sum_m \sum_n \sum_p \sum_l J_m(v_x) J_n(v_x) J_p(v_y) J_l(v_y) \right.$$
$$\times \exp\{-[\alpha + \pi C_x(n-m)/\sqrt{2}]^2 - [\beta + \pi C_y(p-l)/\sqrt{2}]^2\}$$
$$\left. \times \exp[-i\omega t(m+n+p+l)] \right|^2 \qquad (7)$$

As far as equation (7) is concerned, after solving for the time average and, in conjunction with this, unitizing, it is possible to obtain

$$I(\alpha, \beta) = (1/\pi^2 W'^2_0 W'^2) \langle I(\alpha, \beta, t) \rangle$$
$$= \sum_m \sum_n \sum_p \sum_l J_m^2(v_x) J_n^2(v_x) J_p^2(v_y) J_l^2(v_y)$$
$$\times \exp\{-[\alpha + \pi C_x(n-m)/\sqrt{2}]^2 - [\beta + \pi C_y(p-l)/\sqrt{2}]^2\} \qquad (8)$$

(* Here, the various subscripts selected--m,n,p, and l--all are selected with values that run from $-\infty$ to ∞ . The same is true below.)

If the sound fields that are added in the x and y directions have the same frequencies and the situation is such that they have equal powers, that is, $\Lambda_{sx} = \Lambda_{sy} = \Lambda$, $v_x = v_y = v$, as well as $C_x = C_y = C$, then, equation (8) can be simplified to be: 711

$$I(\alpha, \beta) = \sum_m \sum_n \sum_p \sum_l J_m^2(v) J_n^2(v) J_p^2(v) J_l^2(v)$$
$$\times \exp\{-[\alpha + \pi C(n-m)/\sqrt{2}]^2 - [\beta + \pi C(l-p)/\sqrt{2}]^2\} \qquad (9)$$

This is a situation in which acousto-optical modification is often used. If $v_y = 0$, that is, in a one dimensional sound field situation, equation (8) easily becomes a formula expressing the one dimensional modification:

$$I(\alpha, \beta) = \exp(-\beta^2) \sum_m \sum_n J_m^2(v_x) J_n^2(v_x) \exp\{-[\alpha + \pi C_x(n-m)/\sqrt{2}]^2\} \qquad (10)$$

If $v_y = 0$ and $v_x = 0$, that is, a situation in which sound fields are not added, from equation (8), it is possible to obtain the normal Gaussian laser light bundle or beam spacial strength distribution:

$$I(\alpha, \beta) = \exp[-(\alpha^2+\beta^2)]. \quad (11)$$

If one is dealing with a two dimensional correlation field, carrying out the same type of operations, it is still possible to obtain equation (8). This explains the fact that the strength distributions on the focal surface behing L_2 and the phase difference Φ between two dimensional sound fields are not related. At the same time, take equation (8) and, by comparing it to a one dimensional situation, it is possible to know that it is only necessary to select appropriate values for the parameters v and C and it is then possible to realize the simultaneous modification of Gaussian light beams or bundles in the two directions--x and y.

III

In order to quantitatively describe the results of modifications, introduce a "modification factor". From equation (11), it is possible to know that $I(a=0, \beta=0) = 1$, $I(a=0, \beta=1) = I(a=1, \beta=0) = 0.37$. In this way, we can select light strength change situations in which β = 1 positions (or a = 1 positions in conjunction with respectively taking β_0 or a_0 to represent it) to act as measures of the effects of modifications. As is shown in Fig.2, it is possible to define the modification factor to be:

$$G(v, c) = [I(0, 0, v, c) - I(\alpha_0, 0, v, c)]/I(0, 0, v, c) = [I(0, 0, v, c) - I(0, \beta_0, v, c)]/I(0, 0, v, c). \quad (12)$$

This definition is aimed toward the equation (9) situation, that is, it deals with the situation where two dimensional sound fields use one signal source as drive or motive force [3]. This is also the practical situation with two dimensional acousto-optical modifications. Because of this, it has even more practical significance. From Fig.2 one can see that, the smaller the G value is, within the same spacial range (delimited by α_0 or β_0), the more the light strength distribution tends to be rendered uniform. Moreover, it is possible to maintain a fixed relative strength. Fig.'s 3 and 4, respectively, give one the relationship curves G(v,c)-v,c for the c or v parameters. These are calculated on the basis of equation (9). One can see that, when the v value is fixed, there is a requirement for c to be selected within a fixed range, and it is just when this is done that it is possible to obtain satisfactory modification results. For example, when v = 1.5 (corresponding to a moderate power mode), with the point for the optimum selection for the c value in the vicinity of 0.55. At the same time, it is stil 712

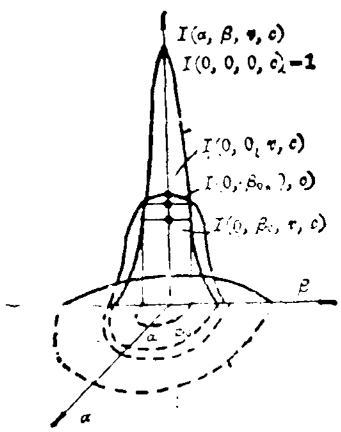


Fig. 2 Factor of the modification

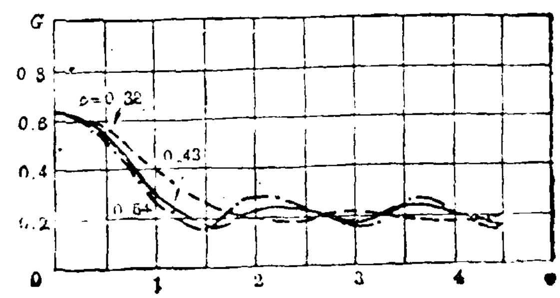


Fig. 3 Curve of $G(v, \alpha_0) \sim v$

possible to see that, after v > 1.5, the selected value of c's influence on modification becomes unclear. Of course, c values still are bound by the original limitations, that is, c is not able to be selected as an excessively large value. If this is not the case, the acousto-optical diffraction presents dispersion spectra and the modification loses its significance [1]. It also cannot be too

small. If it is too small, then, the optical system will be difficult to observe.

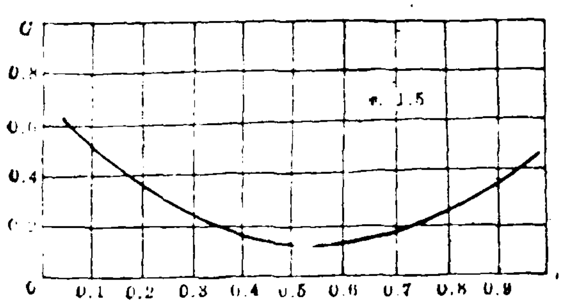


Fig. 4 Curve of $G(v_0, c) \sim c$

Fig.5 gives a classical numerical presentation of a modification. In it, 5(a) is the light strength distribution when v = 0. Obviously, it is a strictly Gaussian form. The other relevent parameters are all appropriate values, that is, $\Lambda_{sx} = \Lambda_{sy}$ = 572 μm. λ = 80 μm. In conjunction with this and due to it, one has $c_x = c_y = c = 0.45$. Fig.5(b) is the modification situation corresponding to when v = 1.5. It is not difficult to see that the light strengths for the vicinity of its center domain are already clearly tending toward homogenization. If one increases acoustic power another degree, for example, selecting v = 2.5, that is, when the situation corresponds to Fig.5(c), then, it is possible to discover that, although the center domain is clearly homogenized, the center light strength, however, still experiences a relatively large drop. Because of this, this type of modification is also difficult to make practical use of. If one makes use of a modification factor evaluation, that is, calculates on the basis of equation (12), then, the G values corresponding to the three types of situations described above are, respectively: G(0,c) = 0.63, G(1.5, c) = 0.18, and G(2.5,c) 7:3
= 0.22, or, the G values using Gaussian light beams or bundles are unitized, that is, one selects g = G(v,c)/G(0,c). The three types of situations described above are, then, respectively, ones with g_a = 1.00, g_b = 0.29, and g_c = 0.35. It is possible to see thatthe second situation, speaking in terms of modification, is very appropriate. In order to compare, we also caluiated out and drew out

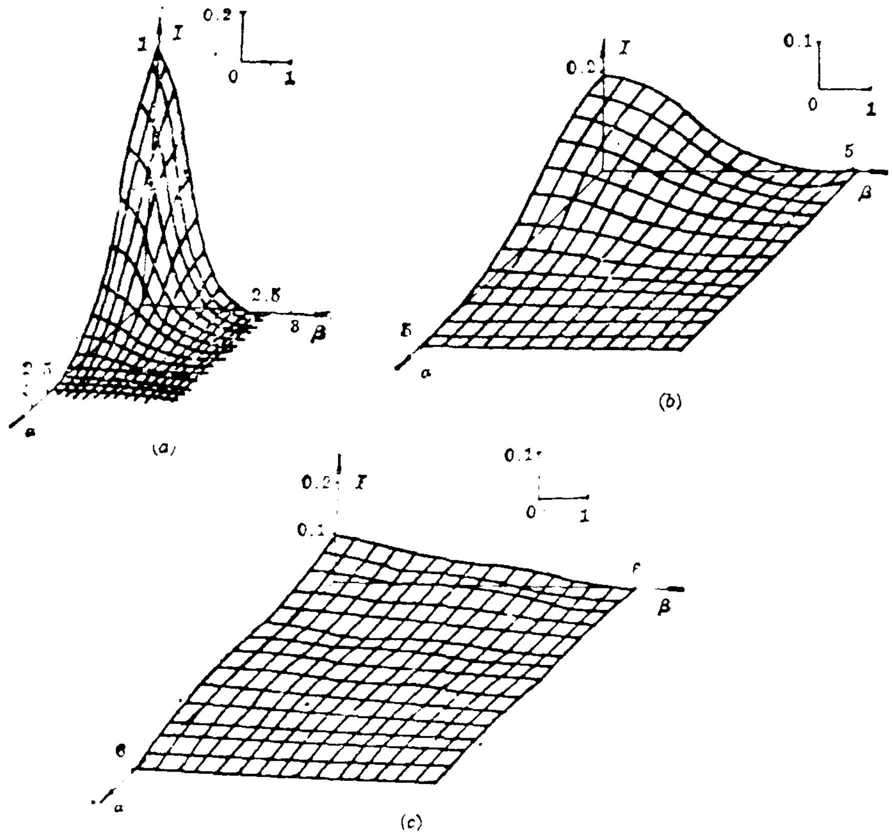


Fig. 5 Gaussian intensity distribution for $c = 0.43$ (a) $v = 0$, (b) $v = 1.5$, (c) $v = 2.5$

For another special type of situation, that is, when the parameter is selected as a relatively large value, the corresponding distribution curve for light strengths (Fig.6). Here, one still selects v = 1.5. However, w = 0.25mm. Because of this, c = 1.54. Due to the fact that one already has $2w > \Lambda_{s(\text{unclear})}$ = 0.57mm, it follows that the spatial homogenization of faculae strengths begins to break up. This situation can be clearly seen from Fig.6.

In order to measure the size of uniform faculae domains to different v values, we can define the coordinate value β (or α) at the 1/e position where the β direction (or α direction) light strength is reduced to the center (α = 0 or β = 0) strength as the uniform faculae radius R. Under this definition, the faculae radii for the various situations calculated from equation (9) in Fig.5 are, respectively, 1, 2.4 and 3.8. As far as different values of v are concerned, they have different R. Moreover, under conditions satisfying the requirement that the faculae radii radiate: in be

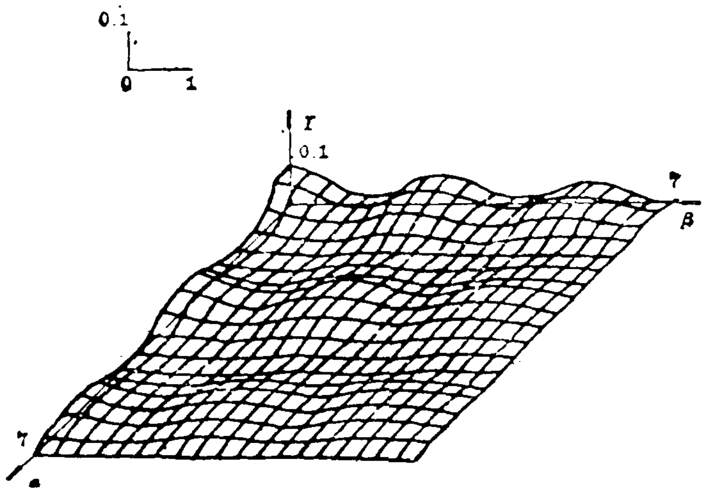


Fig. 6 Gaussian intensity distribution for ($c=1.34$); $v=1.5$

smaller than the acoustic wavelength, the larger the v value is, the larger the uniform faculae radius R also is. However, it is necessary to point out that R is not, as one might expect, better the larger it is. The reason for this is that after R reaches a certain level (that is, v reaches a certain level), the G value will become large. At this time, the light energy density loss is too great. It cannot satisfy the energy densities required by practical applications. Because of this, when the dimension W for the in-radiating [illegible] once fixed, the selecting of the v value that is optimal for application to modification requires using G value minimums as standard. Moreover, it is not possible to take as standard the [illegible] values to measure the size of the faculae areas of uniformity.

The above calculations and analysis are all assisted in their completion by computers. During calculations, the ranges of [illegible] of the values for the subscripts m, n, p, and l in equation (9) are all -10 -- 10. Because of the fact that Bessel functions, when their arguments are $v < 2.4$, have $J_{10} \ll J_{0}$, it follows as a consequence that the results of our calculations and their analysis have a certain precision. Besides this, speaking from theory, after modification, the angle of divergence of the light beams or bundles will be greater

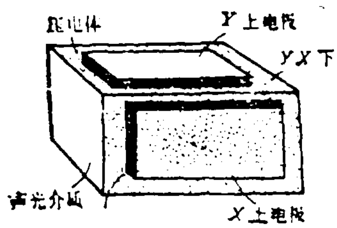
than the angle of divergence of the original Gaussian light beams. If one defines the light beam divergence angle on the basis of the 1/e location where the light strength drops to the center strength, then, the divergence angle corresponding to Fig.5 is 2.1 times the faculae angle of propagation in Fig.5(a).

If the frequency of the sonic field used is dropped down quite low, then, after modification, the angle of divergence of the light beams will be reduced as compared to the divergence angle when the frequency is 10MHz. In this way, after modification, it is still possible to maintain a certain light energy density.

IV

The acousto-optical modulator structure used in two dimensional modification is as shown in Fig.7. This is a type of the so-called intersecting electrod method. It is also possible to make use of 714
photoelectric crystals (for example, niobiate of lithium and other similar substances) the acoustic resonance effects of which [3] form two dimensional sound fields. The experimental apparatus and the one dimensional situation are, on the whole, the same[1]. It is only the form of power for the signal source that is changed into two paths. Due to the fact that the electrode structure, the power output feeder lines, and other similar factors are all the same, it follows then, that it is possible to obtain, in the two directions x and y, an ultrasonic field with the same strengths, that is, having $v_x = v_y = v$.

Fig.8 is a schematic diagram of the experiments. The signal frequency was 10MHz. The amount of power was standardized by the output voltage value ($u \propto v$) of the signal source. Modification results were read out through a scanning photoelectric multiplier tube tied into an X-Y recording instrument. The diameter of the sampling aperture of the multiplier tube was ϕ 0.2mm. Several classical measurement results are shown in Fig.'s 10-12. When the acoustic field is not added ($v = 0$), the Gaussian faculae or light spots and their strength profiles are given in Fig.9. Fig. 10 is the light spot



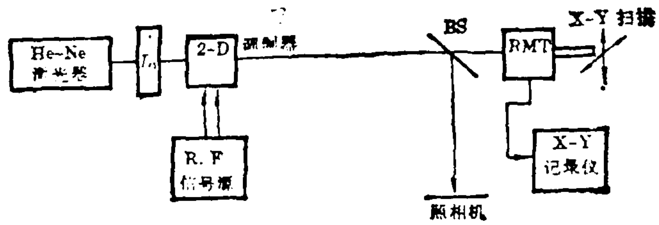
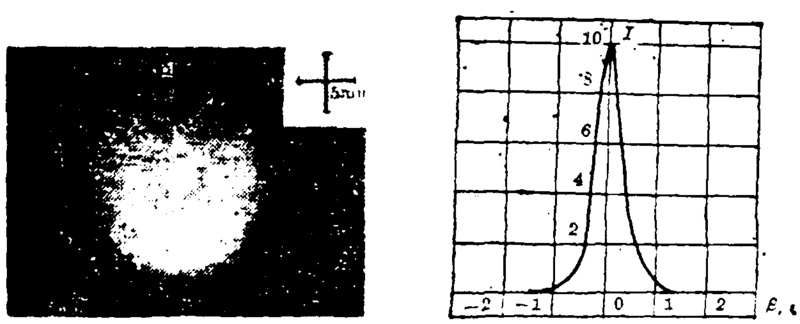


Fig. 7 2-D R-N acoustooptic modulator

Fig. 8 Experimental set-up

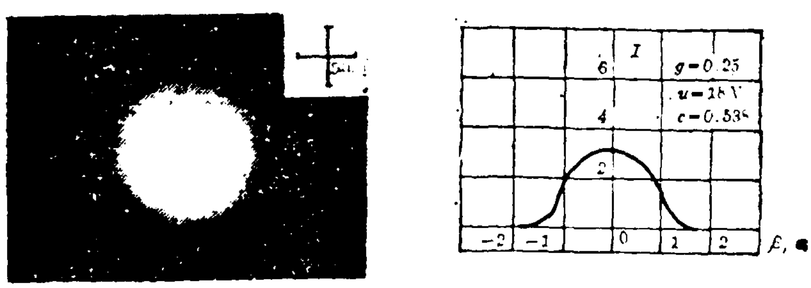
Fig.7 2-D R-N Acoustooptic Modulator (1) Piezioelectric Body (2) Upper Y Electrode (3) Lower Y X Electrode (4) Upper X Electrode (5) Acoutsto-optical Dielectric

Fig.8 Experimental Set-Up (1) Laser Device (2) Modulator (3) Signal Source (4) Camera (5) X-Y Scan (6) X-Y Recording Instrument



(a) (b)

Fig. 9 (a) Gaussian light spot for $v=0$; (b) Intensity profile of light spot ($g=1$, $u=0$, $c=0.54$)



(a) (b)

Fig. 10 (a) Gaussian light spot for output of signal sougth, $u=18$ V;
(b) Intensity profile of light spot ($g=0.25$, $u=18$ V, $c=0.538$)

(v_s = 1550m/s). The piezoelectric body was quartz crystal. The base frequency was 435.5 kHz. The second octave or multiple frequency was 871 kHz. Still on the basis of the equipment set up in Fig.8, but taking out the lens L_1, and, in conjunction with this, changing to the use of 1.8 μm laser devices, the output power is 50mW. The laser bundle or beam directly radiates into the modulator. Because of this, laser beams or bundles actually have light spot diameters of $2w \simeq 1$mm. Taking the 871kHz ultrasonic as an example, the results of measurements were Λ_s = 1.78mm, $c \simeq 0.56$, satisfying the modification requirement. When the acoustic power (situation without matching) is $\sim$ 2.5W, it is possible to obtain relatively satisfactory modifications. At this time, the results of actual measurements of divergence angles is 1.47'. This is 1.4 times the divergence angle ($\approx$ 1.07') for the in-radiating laser light bundle or beam (that is, v =0). This value and the theoretical value (1.6 fold) compare to each other as roughly the same. The exterior shape of the light spots and the light strength distribution curves are roughly the same as Fig.10.

V.

The conclusion is that it is only necessary for light spot dimensions to be smaller than the ultrasonic wavelength, the Gaussian strength distribution of focused laser light bundles or beams be able, under the effects of two dimensional ultrasonic standing waves, to form two dimensional strength profile adjustable light spots, and, in addition, be within a definite range of parameters, and have moderate sonic powers, and, at such a time, the strength distributions of light spot central areas are able to tend toward uniformity. The degree of uniformity and its range are capable of going through adjustments and continuous changes in acoustic power. This is the important point at which this method is better than other methods of modification [4,5]. Because of this, it is unusually suitable for use in circumstances where light spot profiles are adjustable, for example, it will achieve widespread applications in the fields of lasers for medical use and laser heat treatment.

The important disadvantage with this type of method is that, due to the fact that the strength fluctuations [6] of the light spots are two fold around the ultrasonic frequency (which is 20MHz), it follows that it is not suitable for use with short pulse lasers.

This work has benefited in its execution from fruitful discussions with Professor Sheng Qiuqin. Comrade Chen Ping also provided earnest assistance. We express our thanks to both of them. 71

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